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Design and optimization of a novel electrically controlled high pressure fuel injection system for heavy fuel aircraft piston engine

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Abstract The heavy fuel compression ignition engines are widely equipped as aircraft piston engines. The fuel injection system is one of the key technologies that determines the performance of engine. One of the main challenges is to precisely control the injected fuel quantity and flow rate in the presence of pressure fluctuation. This challenge is even more serious for heavy fuel. An original design for electrically controlled high pressure fuel injection system called Multi-Pump-pressure-reservoirs fuel injection System (MPS) was demonstrated to reduce the pressure fluctuation and help keep injection stable. MPS was compared with an ordinary high pressure Common Rail fuel injection System (CRS). This work established one-dimensional AMESim and mathematical models for both CRS and MPS to study the effect of different structures and geometric parameters on the pressure fluctuations. The calculations show that the average fuel pressure fluctuation of MPS can be reduced by 57% for the crankshaft speed of 1900 r/min, and the pressure fluctuation before injection reduced by 100%. It is concluded that the pressure performance of MPS is less sensitive to pressure reservoir volume than that of CRS, and there is an opportunity for further volume reduction.

1. Introduction

The aircraft piston engine is one of the most widely used aircraft power plant. In the very beginning, diesel was the main fuel for aircraft piston engine. However, the power to weight ratio of diesel engine is too low to support aircraft development. Over the last century, the aircraft piston engine used mainly aviation gasoline as fuel under spark ignition combustion mode. In the recent decades, the heavy fuel compression ignition engine, used as an aircraft piston engine,[1–3] has gradually become more predominant, as the power to weight ratio increased greatly with the employment of the super-charger and electrical fuel injection system. The heavy fuel compression ignition aircraft piston engine has the advantage of higher compression ratios, which are matched with high pressure fuel injection systems, leading to lower specific fuel consumption

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and longer cruise duration. Furthermore, heavy fuel has better security and is more suitable for shipboard aircraft.

The fuel injection system is one of the key technologies that determines fuel efficiency and emissions. Typically, a multi-cylinder diesel compression ignition engine employs high pressure Common Rail fuel injection System (CRS).[4] One of the main challenges associated with the CRS is to precisely control the injected fuel quantity and flow rate in the presence of pressure fluctuation in the rail and injector. Pressure fluctuation might affect the stability and consistency of fuel injection and further affect the combustion efficiency of the engine.[5–7] Significant research has been conducted on the influence of different system parameters on pressure fluctuation in CRS.[8–10] Some studies focused on electrically controlled parameters and operating parameters.[11] Some research has designed certain types of damping or compensation assemblies for the common rail.[10] Others have further optimized the structure parameters to reduce pressure fluctuation.[12]

As the electrical technologies develop, pressure variation caused by fuel quantity variation in the rail can be compensated by advanced electrical control methodology.[13] One problem is that the sampling frequency of the transducers is not sufficiently high to respond to high frequency pressure fluctuations caused by pressure wave propagation and reflection, consequently limiting the effect of pressure compensation. Structure innovation and parameter optimization remain important for reducing pressure fluctuations.

The challenge of controlling pressure fluctuation is even more serious for heavy fuel as compared with diesel, as heavy fuel is composed of different types of fuel, which have different characteristics. Heavy fuel for aircraft piston engine refers to aviation kerosene or diesel fuel, including JP-8, JP-5 and diesel. When specific fuel type changes, the characteristics such as density and viscosity all change. Hence, the pressure fluctuation features might also change, which could vary the injection pressure and injection amount and consequently form unstable combustion. To solve the problem, we have to reduce the pressure fluctuation of the high pressure fuel injection system to a certain level which does not affect injection obviously, so that the aircraft piston engine can accommodate to different fuel types. However, there is limited research on specially designed high pressure fuel injection systems for heavy fuel compression ignition aircraft piston engine.

This study demonstrates a novel electrically controlled high pressure fuel injection system called Multi-Pump-pressure-reservoirs fuel injection System (MPS). The new structure can reduce the influence between cylinders, and thus greatly decrease pressure fluctuation and stabilize injection and combustion with different fuel types. Compared with an ordinary CRS, the fuel pump and common rail of MPS are divided into several parts according to the number of the cylinders. In fact, no longer is there a common rail, which is now replaced by several pressure reservoirs. Each single unit pump and pressure reservoir for one cylinder is integrated into one component as a Pump-pressure-Reservoir (PR) complex. As a result, fuel supply and fuel injection only occur once in the PR during a crankshaft cycle, and the damping time of pressure fluctuation is much longer.[14]

This work established one-dimensional AMESim and mathematical models for CRS and MPS separately to study the effect of different structure and geometric parameters on the pressure fluctuations.[15,16] Based on the models, the structure and dimensions of PR of the MPS were optimized to reduce the pressure fluctuations. The calculations show that, compared with CRS, the average fuel pressure fluctuation of MPS induced by periodic fuel pumping and injection can be reduced by 57% for the crankshaft speed of 1900 rpm, and the pressure fluctuation before injection is reduced by 100%.

2. Physical and mathematical model of fuel dynamics in CRS and MPS

2.1. Physical models

To begin with the modelling details of CRS and MPS, we briefly introduce two systems. Fig. 1 shows the sketch of CRS, where the main components include a fuel tank, a low pressure supply system, a high pressure inline pump or rotor pump, a delivery valve, a common rail, an electronic control unit, and several electronically controlled fuel injectors. The low pressure supply system supplies assigned amount of low pressure fuel to the pump according to the Electrical Control Unit (ECU). The high pressure pump elevates the fluid pressure to a range of 100–200 MPa, which is stored in the common rail as a pressure accumulator, and injected by the electronically controlled fuel injectors with flexible injection time and stable pressure.

Fig. 2 shows the sketch of MPS. MPS has almost the same components as CRS, except for the high pressure inline pump or rotor pump and the common rail, which are replaced by several PRs according to the number of the cylinders in the engine. The PRs can be placed separately besides the cylinders or combined in a pump box, according to the installation space of the piston engine. In this research, we designed an MPS with six PRs and injectors for a six-cylinder heavy fuel aircraft piston engine.

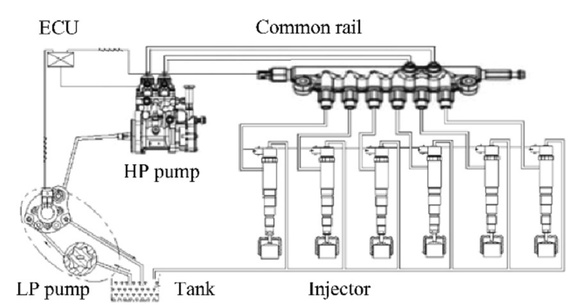

Fig. 1 Sketch of CRS for a six-cylinder engine.

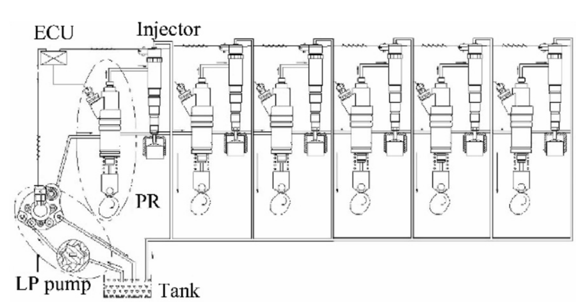

Fig. 2 Sketch of MPS for a six-cylinder engine.

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